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EFFECT OF EXTRANEOUS COLOR-CODED TARGETS ON IDENTIFICATION OF TARGETS ON CRT DISPLAYS

by

S. M. Luria
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and
Robyn Bivenour

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EFFECT OF EXTRANEOUS COLOR-CODED TARGETS ON

IDENTIFICATION OF TARGETS ON CRT DISPLAYS

by

S. M. Luria, David F. Neri[1], Matthew J. Shim, and Robyn Bivenour[2]

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
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SUMMARY PAGE

THE PROBLEM

To determine if the ability to match a color coded target track is degraded by the presence of several other target tracks of different colors.

THE FINDINGS

Neither response speed nor color confusions in the presence of the extraneous target tracks was degraded.

APPLICATION

The color coding of multiple target tracks on such visual displays as the broadband waterfall sonar display will not degrade the speed or accuracy of identifying a specific target track.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Naval Medical Research and Development Command Research Work Unit Number 65856N - M0100.001-5003. It was submitted for review on 20 September 1989, approved for publication on 16 January 1990, and has been designated as Naval Submarine Medical Research Laboratory Report No. 1154.

ABSTRACT

Subjects matched a vertical target line presented in one of 10 colors to the set of 10 colors. The target line was presented either in isolation or together with 5 additional colored lines. Neither mean reaction time nor the number of matching errors increased when the extraneous lines were present, and the types of color confusions remained reasonably constant.

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INTRODUCTION

Sonar operators, using the broadband "waterfall" display, search for a thin line which constitutes a target track. Although current displays are monochromatic, color may well be added in the future. To examine the usefulness of color coding the target tracks on such displays, we have measured the response times of individuals to lines coded with different colors (Luria, Neri, & Jacobsen, 1986); compared different sets of colors (Neri, Luria, & Jacobsen, 1985); measured the effect of varying the background colors (Neri, Kobus, et al., 1985) and brightness (Jacobsen, 1986); and measured the effects of different colors of ambient lighting (Neri, Luria, & Kobus, 1986). These studies have shown that operators can handle as many as 20 different colors without undue confusion, that color recognition is best with a background of intermediate gray rather than white or black, that performance is the same with black and blue backgrounds, and that the color of the ambient light does not affect performance with CRT displays.

Currently, the basic problem is how many different colors can be used to code different tracks without undue confusion. We have found, as noted above, that a surprisingly large number of colors can be recognized and recalled without undue confusion on the part of the operator (Jacobsen & Neri, 1985; Jacobsen, 1985). These studies, however, presented only one color-coded target at a time. The present study sought to determine to what extent the CRT operator's performance is affected by the presence on the screen of several target tracks, in different colors. If the operator is trying to identify one specific target track, will his performance be degraded by the presence of other target tracks in the vicinity?

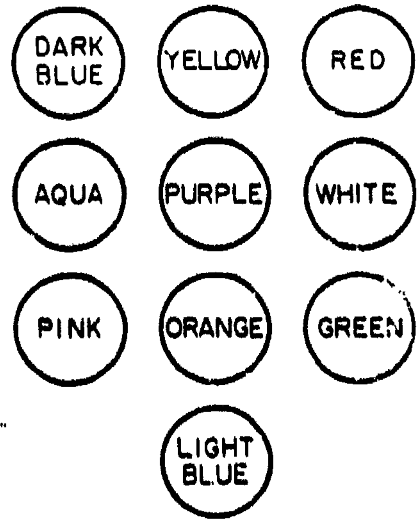
METHOD

Subjects

Twelve staff members of the laboratory volunteered to participate. All were color normal according to the Hardy-Rand-Rittler pseudoisochromatic plates.

Apparatus

The stimuli were presented on an Advanced Electronics Design, Inc. Color Graphics and Imaging Terminal, Model 1024, under the control of a Digital PDP 11/04 minicomputer. A series of circular stimuli were arranged in the pattern of a telephone pushbutton keypad: a 3x3 matrix plus one more stimulus centered below these (Figure 1). Each circle was 1 cm in diameter, separated by 0.75 cm from the adjacent stimulus. The total arrangement measured 4.5 cm wide by 6.2 cm high.



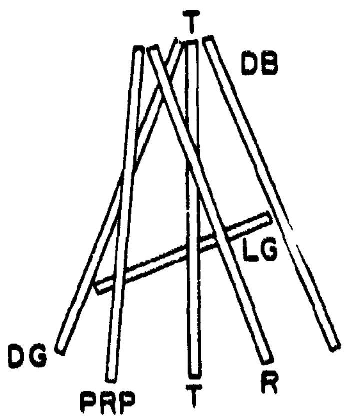


Figure 1. The display. The target line (T) was presented either alone or with the other five lines colored dark blue (DB), dark green (DG), light green (LG), purple (PRP), or red (R).

The circles were of different colors and were always present. No attempt was made to equate the brightnesses of the colors. Rather, differences in brightness were chosen by eye which appeared to help differentiate them; thus, for example, both a light and a dark blue were included in the set. The 10 colors were judged to be distinctly different by four people with normal color vision. The C.I.E. coordinates and luminances of the 10 colors were measured with a Photo Research Spot Spectra Scan Spectroradiometer, Model PR 703A, and are listed in Table 1 and shown in Figure 2.

Table 1

The colors and their chromaticity coordinates and luminances

Target Color	Chromaticity x	y	Luminance cd/m^2
Dark Blue	.15	.09	2.7
Yellow	.43	.45	42.7
Red	.61	.35	17.8
Aqua	.25	.38	9.8
Purple	.27	.16	2.2
White	.29	.31	44.7
Pink	.37	.35	13.1
Orange	.56	.36	7.0
Green	.30	.52	31.4
Light Blue	.17	.13	12.0

Distractor Color	Chromaticity x	y	Luminance cd/m^2
Dark Blue	.16	.13	2.1
Dark Green	.30	.55	26.4
Light Green	.30	.59	44.1
Purple	.28	.21	5.9
Red	.61	.36	13.8

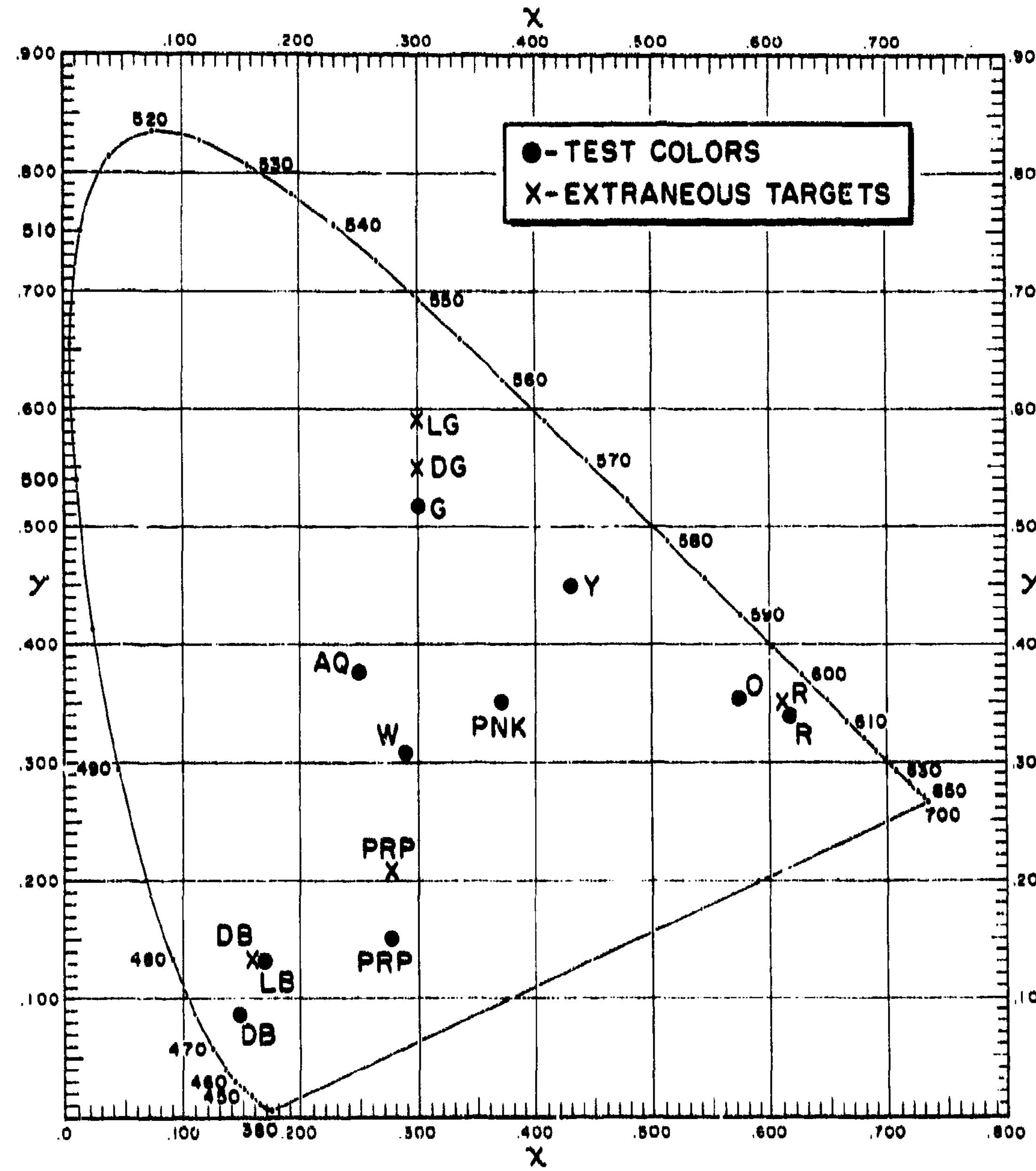


Figure 2. C.I.E. chromaticity coordinates of the stimuli.

The target was a vertical line 3 cm long and 1 mm wide. It was presented in the center of the display with the top of the line 6 cm below the lowest circle. At the viewing distance of about 60 cm, the circular stimuli subtended .95 deg visual angle; the vertical line subtended 2.9 deg visual angle in length and about 0.01 deg visual angle in width.

The target line was presented either alone or in the presence of five other lines (Figure 1). The extraneous target lines were red, dark blue, purple, light green, and dark green. These extraneous lines were always in the same location, as shown in Figure 1. Their C.I.E. coordinates and luminances are also listed in Table 1.

The subjects viewed the display in a dimly lit room. The mean luminance range of the stimuli was about 2 to 45 cd/m^2 against a CRT background of about 0.07 cd/m^2.

A telephone pushbutton response keypad was placed on a table in front of the subject and wired to the computer. The arrangement of its ten keys was identical to that of the circular stimuli on the display.

Procedure.

Each subject was first given a series of training trials before starting the experiment. The outlines of the 10 circles were always visible in the appropriate color, but unfilled. One second after a warning tone, one of the circles filled with its color. The subject was instructed to press the button on the keypad that corresponded to the position of the filled circle as quickly as possible. The button press caused the circle to return to its original unfilled condition. After a two second delay, another warning tone sounded, followed by another circle being filled. No color matching was involved. During the training trials, the circles were filled in random order until the subject had made 7 correct responses to each circle. The training session thus comprised 70 correct responses. The computer recorded the button which had been pushed and the reaction time (RT). Incorrect button pushes were not included in the mean RTs. The training period allowed the subject to learn the positions of the colors. The training trials were continued until the RTs were no longer improving. The training sessions were continued until the RT had no longer decreased for five sessions. The stable mean RTs to all the colors in these final sessions indicated the times required to respond using each button in the keypad without having to match the colors.

During the experiment, the vertical target line appeared 1 sec after the warning tone. It was identical in color to that of one of the circles. The subject's task was to match the line to the correct color in the set as quickly as possible by again pressing the corresponding button. Half of the subjects were first presented with the target lines in isolation, and half were first presented with the target plus the distractor lines. In the latter condition, the distractor lines were always present on the display. Each of the ten colors was presented in random order until the subject had made seven correct matches to each color.

RESULTS

Reaction time. To determine the time taken to match each color, one must correct for different RTs to the different buttons. The first step, then, was to determine the RT to the button for each color. Figure 3 shows the mean RTs to the 10 buttons in the keypad. As expected, RT was fastest to the three buttons in the center, slower to the top three buttons, and slowest to the four bottom buttons.

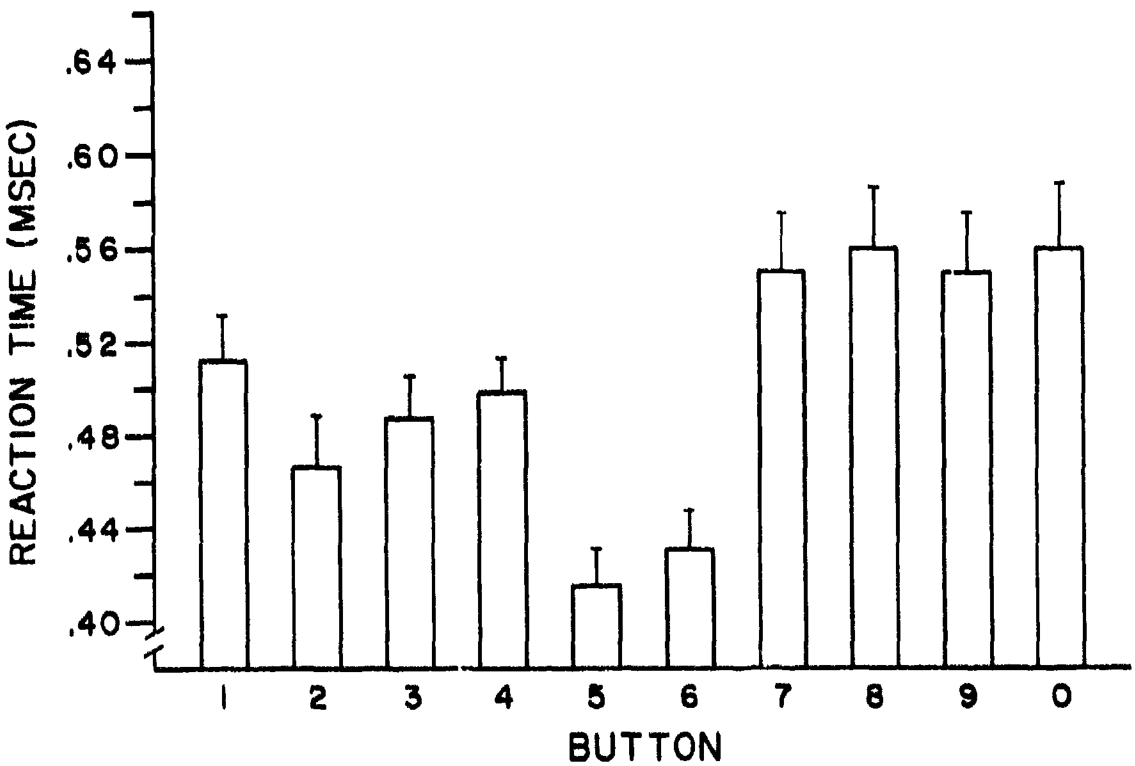


Figure 3. Mean reaction times to the ten positions at which the colors were presented. The lines above each bar are standard errors of the mean.

To determine the time taken to match each color, the response time to each button was subtracted from the response times to each color. This eliminated the motor component of the color-matching response. The resulting RTs for each color, both when the target line was presented alone or in the presence of the other target lines, are presented in Figure 4. The mean RT was faster with the multiple targets present than when the target line was presented in isolation (316 msec $\pm$ 117 vs 343 $\pm$ 145). For every color except orange and green, RT was faster with the multiple display. This difference fell just short of significance according to an analysis of variance ($F(1,9)=3.38$, $p < .06$). The two sets of reaction times were highly correlated ($r = .87$, $p < .01$) indicating that the subjects were responding quite similarly to the colors with the single or multiple targets.

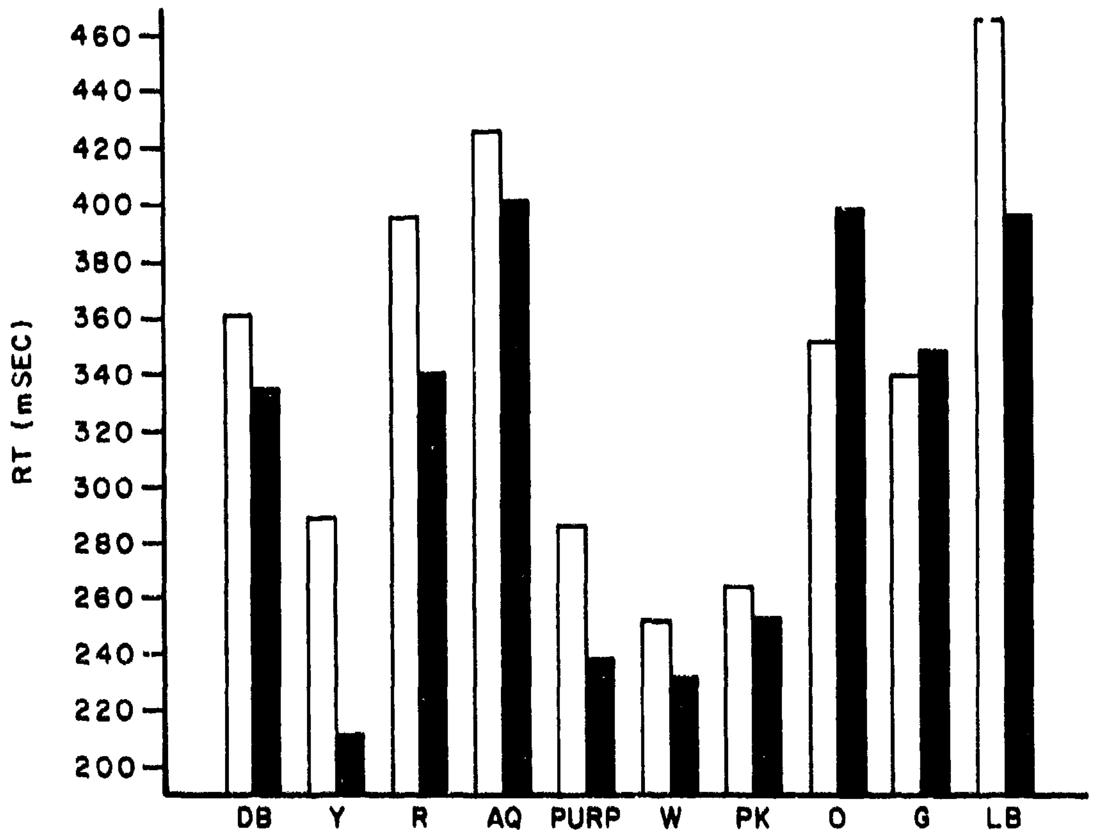


Figure 4. Mean time taken to match the color of the target line to the set of colors when it was presented either alone (open bars) or with the extraneous lines (filled bars).

Table 2

Number of Mismatches With (D) and Without (N) Distractors

Mismatches

Target Color		Dark Blue	Y	R	AQ	PUR	W	PNK	O	G	Light Blue	Total
Dark Blue	N		2								17	19
	D		2			6		1			26	35
Yellow	N	1		1	3	1	1	1		1	3	11
	D				1	1	4			1	1	8
Red	N		2						58	5	4	69
	D		9			13	2		64	4	3	95
Aqua	N	1	1				1	5	1	61		70
	D	3				1	1	7	2	45		59
Purple	N		2		1			1	3		1	8
	D		1		1			2	3			7
White	N		6	1								7
	D		3	1	1			1		2		8
Pink	N		1		12	1			2		2	18
	D	2	2		5				2			11
Orange	N			85		7		3			9	104
	D			30	5	10		1			2	48
Green	N		2	2	13		5					22
	D		3	3	4	2	5				1	18
Light Blue	N	61	1	4		2			7	3		78
	D	79		1	2	4			6	3		99

Mismatches. The subjects made a total of 406 mismatches when the target lines were presented alone and only 384 mismatches when the extraneous target lines were present (Figure 5). Table 2 lists the mismatches made by all the subjects to each color with the single and multiple targets. The differences in the total number of mismatches for each color with the single and multiple targets was not significant, according to the Wilcoxon matched-pair signed-ranks test. The correlation between the number of mismatches with and without the distractors for each color is .80 ($p < .01$), again indicating similar performance in the two conditions.

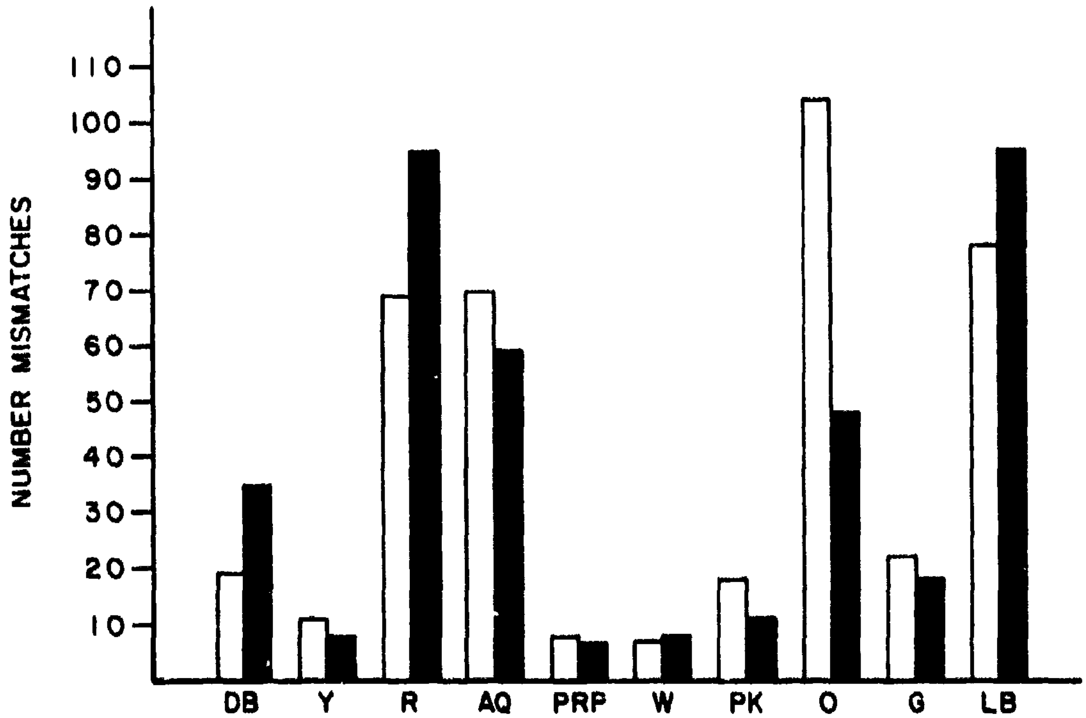


Figure 5. Total number of color mismatches made when the target line was presented alone (open bars) or with the extraneous lines (filled bars) in each color.

Many of the mistakes were made only once during a given run, suggesting that the subject was not confused as to the color but had simply made some sort of motor error. For example, Table 2 shows that orange was matched to light blue half a dozen times in both conditions. This is certainly not a color confusion; and indeed the button for orange (button 8) was immediately above the button for the correct response (button 10). Obviously, the subjects simply did not move their finger down far enough on the keypad. The only mismatch to light blue which occurred a large number of times was dark blue, and this is the only mistake that can be interpreted as a color confusion. But light blue (button 10) was mismatched to orange (button 8) a small number of times; it must be concluded that the subjects simply moved their finger down too far on the keypad.

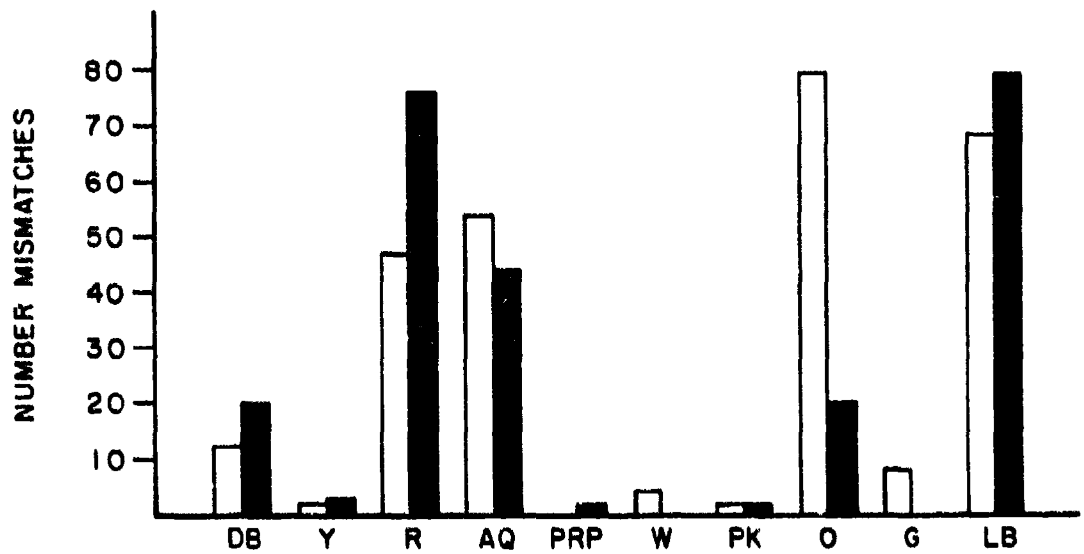


Figure 6. Total number of color mismatches made when the target line was presented alone (open bars) or with the extraneous lines (filled bars) when the matching errors which occurred only once during a run have been removed.

Table 3

Number of Mismatches with Solitary Errors per Run Removed

With and Without Distractors

Mismatches

Target	Color	Dark Blue	Y	R	AQ	PUR	W	PNK	O	G	Light Blue	Total
Dark	N										12	12
Blue	D		2								18	20
Yellow	N				2							2
	D						3					3
Red	N								47			47
	D		4			10			59		3	76
Aqua	N							2		52		54
	D							3	2	39		44
Purple	N											0
	D								2			2
White	N		4									4
	D											0
Pink	N				2							2
	D								2			2
Orange	N			71		6					2	79
	D			18		2						20
Green	N				8							8
	D											0
Light	N	63			3				2			68
Blue	D	79										79

If we ignore all the mismatches which occurred only once during a run, we are left with those which much more likely indicate a color confusion. Table 3 and Figure 6 give that data. We are left with a total of 276 errors with the single target and 246 errors with the multiple targets, but the general picture is unchanged.

Four colors, red, aqua, orange, and light blue, resulted in a sizable number of confusions. When the extraneous target lines were present, the number of confusions was reduced for the orange target, somewhat increased for the red, and remained about the same for the other two.

With the single or multiple targets, the main confusions were light blue for dark blue, dark blue for light blue, orange for red, red for orange, and aqua for green. Interestingly, Table 3 shows that, with the single or multiple display, when dark blue was the target, it was confused with light blue only a few times, whereas light blue was confused with dark blue many times. Similarly, when aqua was the target, it was confused with green many times; yet when green was the target, it was confused with aqua only a few times. In contrast, red and orange were confused with each other more equally.

DISCUSSION

The purpose of this study was to determine the effect of the presence of several colored targets on the performance of an observer trying to attend to one of the targets. Would the presence of several targets in other colors degrade or enhance the ability to deal with one specific target? These results show that the additional target tracks did not degrade either response time or the color matching. Indeed, both the mean RT and the total number of mismatches were lower with the multiple targets.

In the presence of the extraneous target lines, the mean RT decreased for 8 of the 10 colors and increased somewhat only for orange and green. Perhaps of more interest, the number of mismatches changed appreciably for only red and orange. With the multiple display, the number of mismatches increased from 69 to 95 for red but decreased from 104 to 48 for orange. If we eliminate from consideration the errors occurring only once during a run, then the number of errors increased for red from 47 to 76 and decreased from 79 to 20 for orange. On the other hand, the number of confusions between light and dark blue increased somewhat in the presence of the extraneous target lines.

The improvement in RT may result from the presence of the extraneous lines serving as comparison colors which are immediatley adjacent to the target line, are thus very convenient, and permit faster judgments.

There is also some suggestion, however, that there may often be a trade-off between speed and accuracy for colors which are difficult to match. According to both RT and error rate, the colors which are difficult to match are dark blue, red, aqua, orange, and light blue. For every color except aqua, RT was less and error rate greater in the presence of the distractors. The improvement in speed in the presence of the distractors often tends to be balanced by an increase in errors.

Of considerable interest is the surprising lack of symmetry or "transitivity" between certain pairs of colors. When light blue was the target, there were a very large number of confusions with dark blue; yet when dark blue was the target, there were relatively few confusions with light blue. This was true with both the single and multiple targets. Similarly, when aqua was the target, there was a large number of confusions with green; but when green was the target, there were virtually no confusions with aqua. This is in contrast with the results for red and orange. The same phenomenon was found in a previous color-matching study (Luria, Neri, & Jacobsen, 1986).

A lack of transitivity has been found with various psychological variables, but they have typically involved spatial responses. Chief among them, for example, is the assymetry in processing right and left or above and below (Olson and Laxar, 1973). Indeed, Howard (1982) has argued that the so-called edge detectors in the visual cortex are best called anti-symmetrical detectors. A lack of transitivity has been found involving perception of simultaneity (Sekuler,Tynan, & Levinson, 1973; Mayzner and Agresti, 1978), but again this involved differences in direction. One would expect fundamental sensory responses to be transitive as, for example, the results of Corwin and Boynton (1968) in an experiment dealing with the perception of simultaneity of flashes of light. The lack of transitivity found in our studies is very interesting; the explanation is not clear.

In summary, these results indicate that the presence of several color-coded target targets does not in general degrade the ability to deal with one specific target. Color-coding can be used effectively to differentiate several target tracks on such displays as the sonar broadband waterfall display.

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ENDNOTES

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